Development of an Inflatable Supersonic Tension Cone Decelerator

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Outline

- Decelerator technology state-of-the-art
- Previous IAD development efforts
- Overview of Tension Cone
- Outline of present tension cone development

Decelerator Technology State-of-the-Art

- Current planetary missions are pushing aerodynamic decelerator technology to its limits
  - Aeroshell and parachute systems predominantly derived from Viking era design and validation
  - Mars Science Lab is likely at the edge of current capability in landed mass

- Aeroshells constrained by launch vehicle fairing
  - Presently limited to ~5m

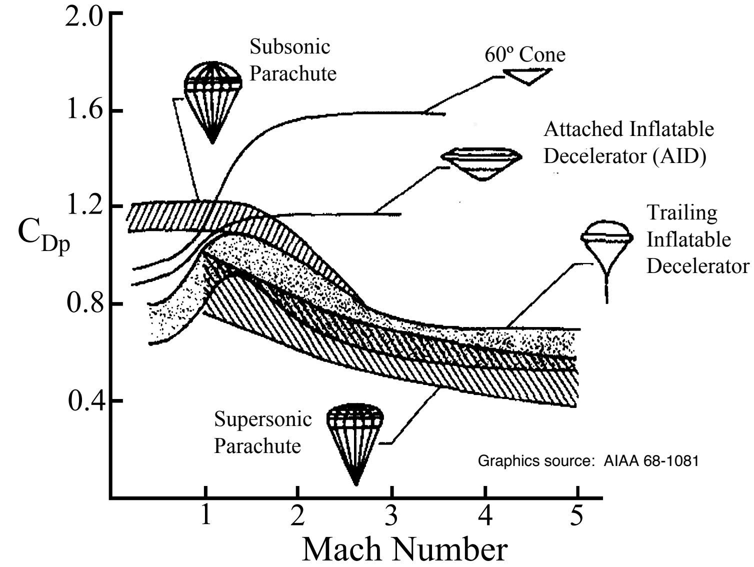
- Parachutes constrained by size, deployment conditions, and poor performance at increasing Mach numbers (M > 3)

	Viking	Pathfinder	MER	Phoenix	MSL
Aeroshell Diameter (m)	3.5	2.65	2.65	2.65	4.6
Aeroshell C_DA (m^2)	15	9	9	9	27
Chute Diameter (m)	16	12.5	14	11.5	19.7
Chute C_DA, approx. (m^2)	118	81	96	69	167
Useful Landed Mass (kg)	244	92	173	167	775
Deployment Mach Number	1.05	1.71	1.82	1.60	2.00

*C_D's approximated using nominal MSL chute performance

Decelerator Technology State-of-the-Art

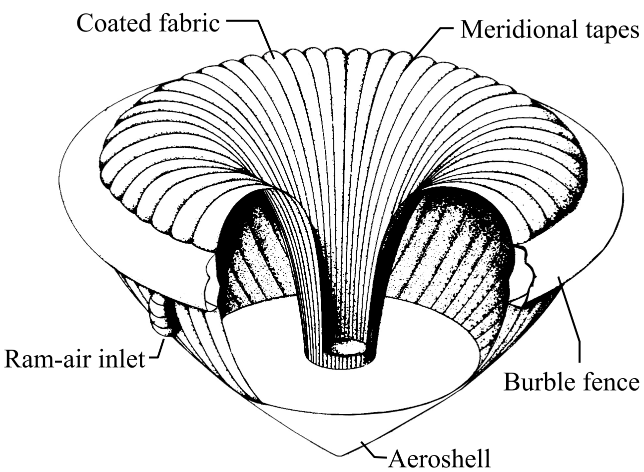
- Supersonic Inflatable Aerodynamic Decelerators (IADs) represent potential upgrade path for entry technology
  - Can act as a bridge towards hypersonic inflatable decelerators
- However, technological maturity requires advancing knowledge in multiple areas of inflatable decelerators
  - Configuration
  - Static aerodynamics
  - Aeroelastic characteristics
  - Deployment mechanics
  - Material behavior and selection
  - Manufacturing/assembly methods
  - Integration with entry vehicle
  - Fluid-structural interaction



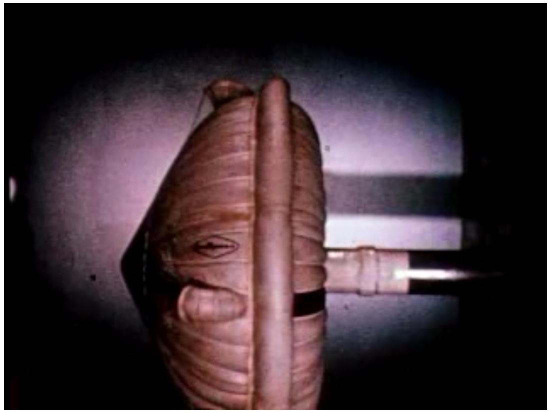
- Technology maturation required to retire uncertainties

Previous IAD Development Efforts

- Historically, variety of IAD concepts considered
  - Predominantly trailing devices, some attached
- A significant amount of work was performed to mature the AID concept during early 60's and mid 70's
  - Initial work focused on shape and structural isotensoid theory
  - Large scale (4.9m diameter) helicopter drop tests
  - Smaller scale (1.4m & 1.5m) supersonic wind tunnel tests
    - Mach 2.2 - 4.5, AOA 0º-10º, Dyn. Pres. > 74.5 psf
- Results of tests showed excellent correlation with basic theory used for design
  - Pressure distribution and aerodynamic coefficients matched well with modified Newtonian theory at high supersonic (M > 3) speeds
  - Experimental inflation loads and times matched with those estimated from simple isentropic flow analysis
- Design and testing approach used for AID program can serve as a blueprint for present effort



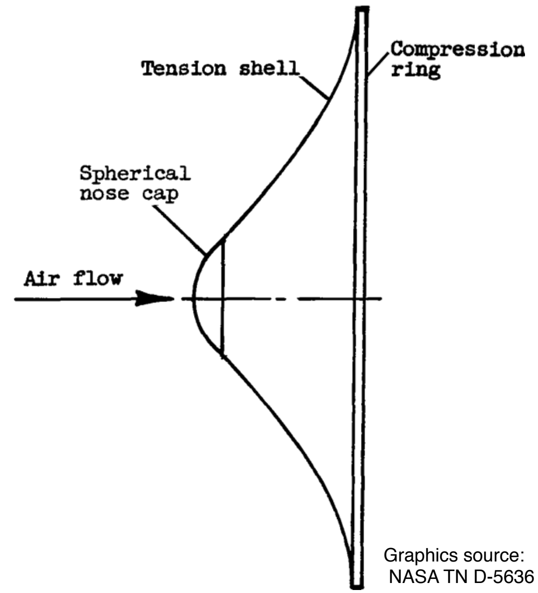
Graphics source: NASA TN D-5840



Movie still from Technical Film Supplement L-1080

Next Step

- Although the isotensoid AID configuration is well developed, alternative configurations may be more optimal
- Development effort underway for a Tension Cone IAD



Graphics source: NASA TN D-5636

Tension Cone

- More recent literature refers to it as a hypercone
- Essentially a tension shell held in place by a torus and used for supersonic (vs. hypersonic) deceleration

Advantages

- Reduced material surface area
- Improved drag coefficients
- Large body of work on shape and structural theory
- Direct linkage to entry decelerator configuration

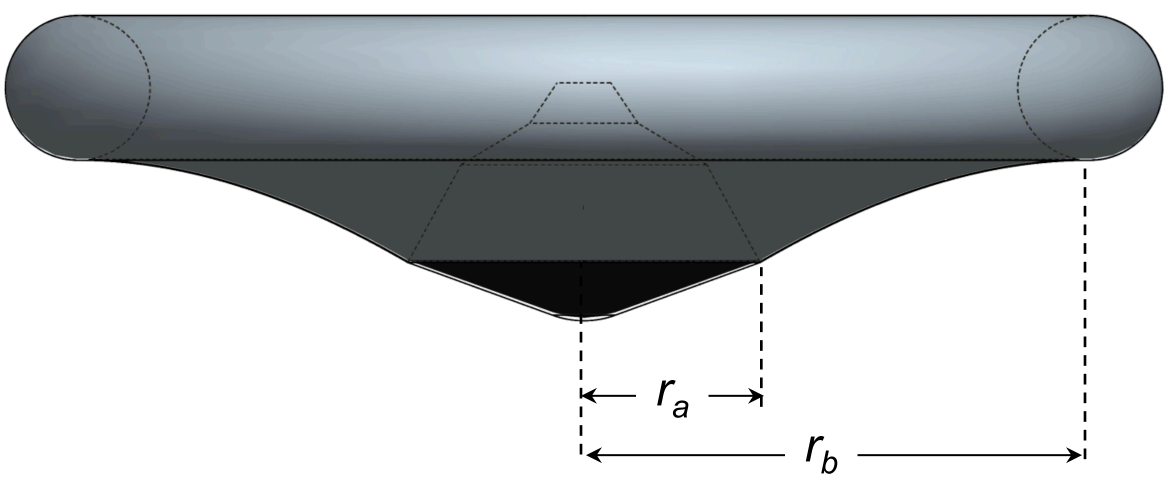
Disadvantages

- Requires separate inflation system
- Variable meridional stresses
- Fabrication specifics still largely undeveloped
- Complex buckling behavior
- Shape and structural theory still somewhat unproven, especially at off-design conditions (α, q, etc.)

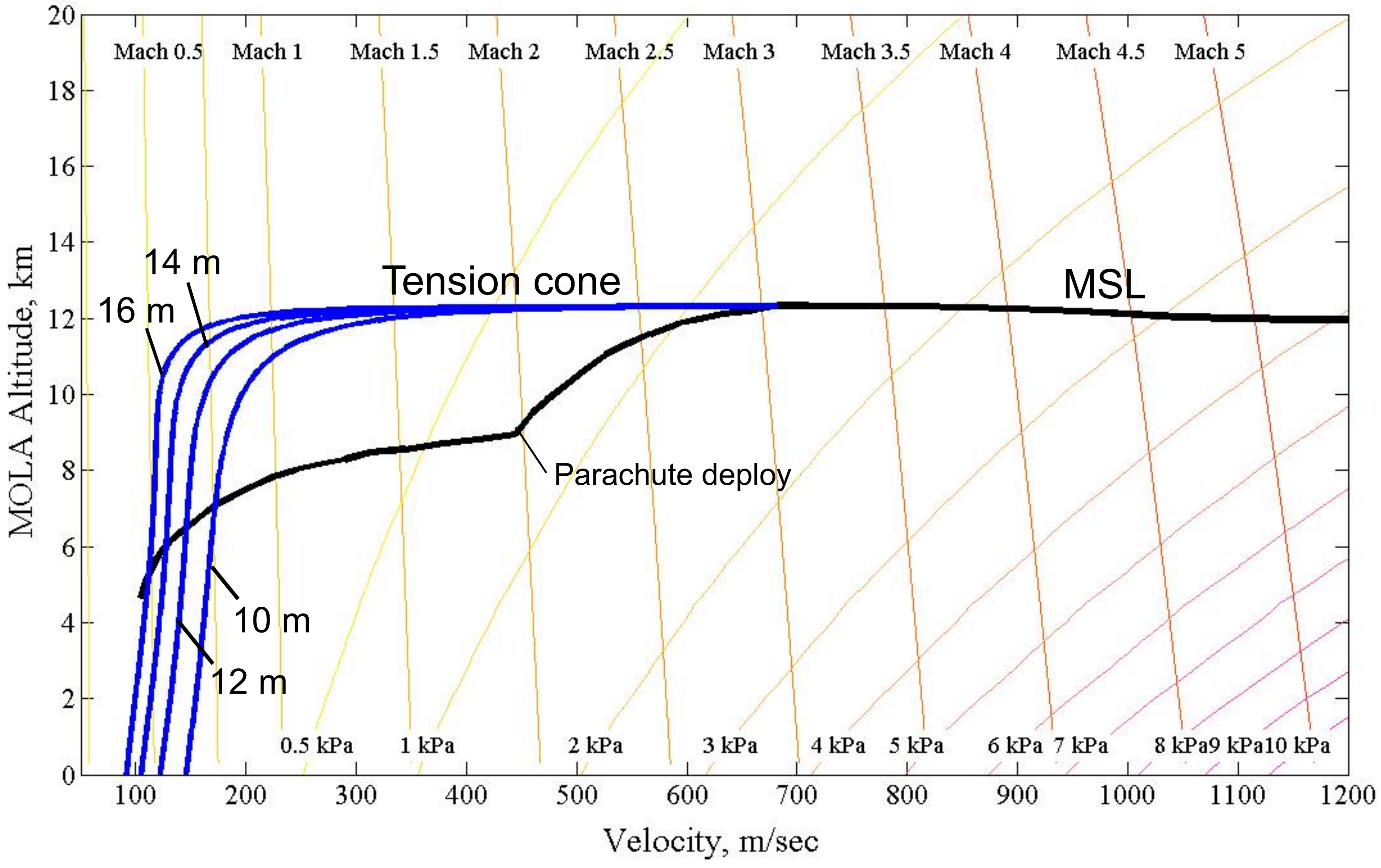
Tension Cone Theory

- Tension cone shape derived on basis of keeping entirety of thin shell under tension to resist deformation
  - Tension in shell resisted by a compression ring (inflated torus)

- Coordinates for tension shell can be determined as a function of only a few variables
  - Pressure distribution (e.g. Newtonian, uniform)
  - Drag coefficient for tension shell shape
  - Ratio of tension shell radius to forebody radius (r_b/r_a)
  - Ratio of circumferential shell stress to meridional shell stress (assumed constant)

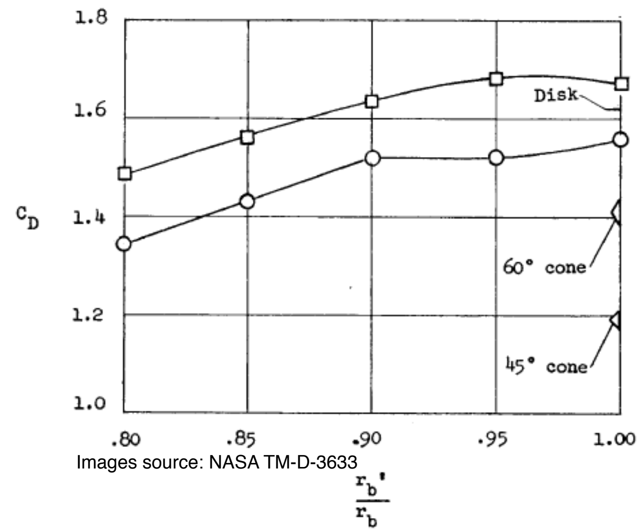


Example Application - MSL Entry

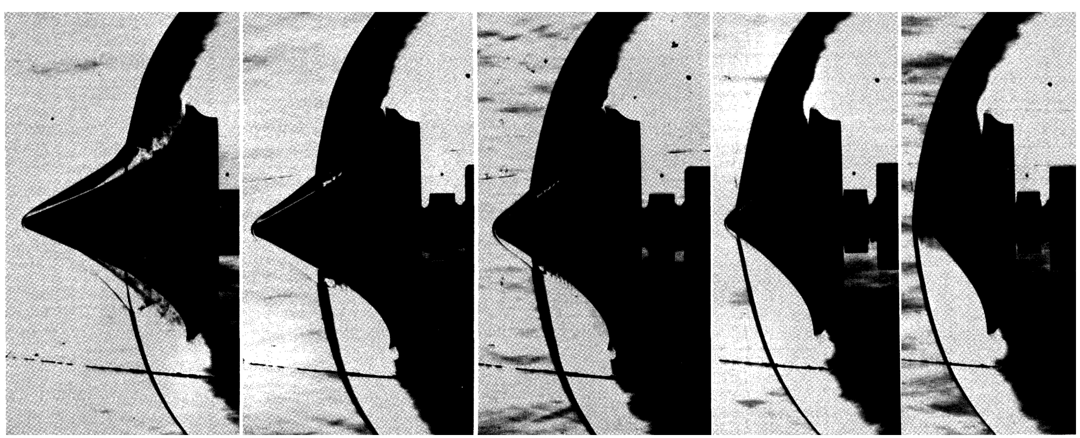


Historical Development Efforts

- Initial investigations performed in late 1960's
  - Focused on static aerodynamics of rigid tension cones
  - Examined variations in cone angles, nose bluntness, and shoulder radii
- Results generally favorable
  - Improved drag
  - Decent stability
  - Some concerns on flow stability



Images source: NASA TM-D-3633

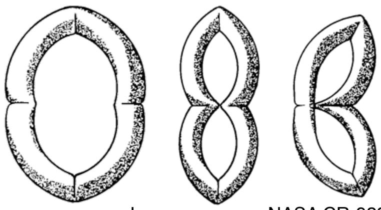


21.5º 27.0º 31.8º 38.3º 47.0º

Compression Ring Design

- Later work focused on structural aspects of the compression ring
  - Pressurized torus seen as favorable solution
- Structural considerations involve localized buckling of membrane wall, in-plane buckling, and out-of-plane buckling
  - Buckling theory for pressurized rings developed for multiple loading conditions
- Experimental efforts aimed at validating theory focused on static testing using vacuum bag and underwater testing
  - Theory not validated under simulated flight conditions

In-plane buckling



Images source: NASA CR-929

Out-of-plane buckling

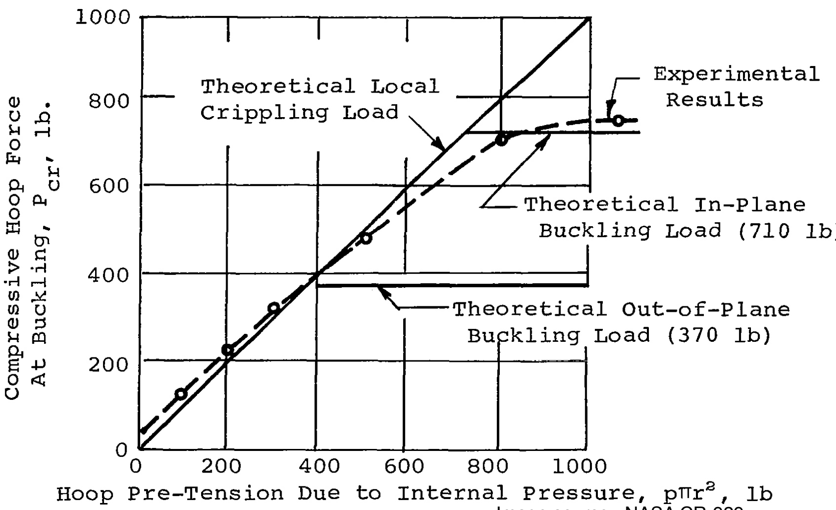
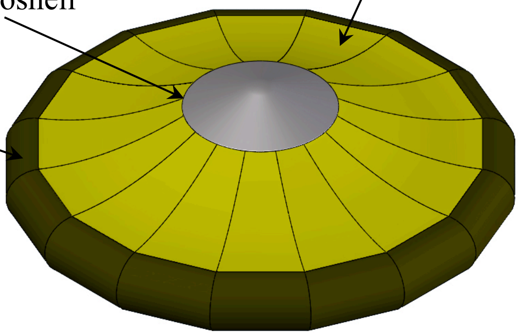


Image source: NASA CR-929

Present Efforts

- Development of Tension Cone concept part of larger Program to Advance Inflatable Decelerators for Atmospheric Entry (PAI-DAE)



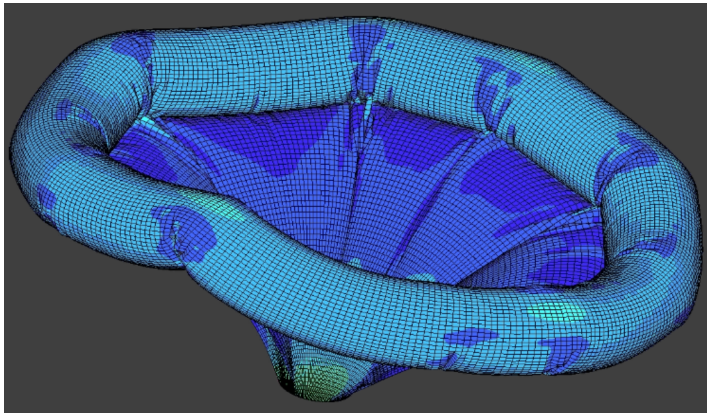
Wind Tunnel Testing

- Two weeks in Glenn Supersonic 10' x 10'
- Incremental testing (three configurations)

Objectives

- Establish aerodynamic database in supersonic regime
  - Mach up to 3.5, Dyn. Pres. up to 10 kPa
- Explore aeroelastic behavior on a flexible tension cone
- Explore inflation and deployment mechanics on an inflatable structure
- Validate tension cone structural and shape theory
- Acquire data useful for validating fluid-structure interaction codes

Future work and conclusions



Fluid Structure Interaction Analysis

- Coupling of high fidelity CFD and structural analysis codes
- Provides capability to analyze and predict behavior of flexible aerodynamic decelerators
- For the most part unvalidated

Follow on testing

- Ballistic range dynamic stability evaluation
- Small (3-5 m) and large scale (15 m) high altitude balloon drop testing
- Sub-orbital sounding rocket tests

Conclusions

- IAD maturation required for future planetary exploration
- Tension cone development program represents logical step in IAD evolution
  - Clear upgrade path to atmospheric testing and hypersonic configuration